academicJournals

Vol. 12(35), pp. 2692-2703, 31 August, 2017
DOI: 10.5897/AJAR2017.12474
Article Number: 12776D865777
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effect of cutting time on agronomic and nutritional characteristics of nine commercial cultivars of *Brachiaria* grass compared with Napier grass during establishment under semi-arid conditions in Rwanda

Mupenzi Mutimura[1]*, Cyprian Ebong[1], Idupulapati M. Rao[3,4] and Ignatius V. Nsahlai[2]

[1]Department of Animal Production, Kigal Rwanda Agriculture Board (RAB), P. O. Box 5016 Rwanda.
[2]Department of Animal Science and Poultry Science, Earth and Environmental Sciences, University of KwaZulu-Natal, School of Agricultural, Pietermaritzburg Campus, Private Bag X01, Scottsville, 3209, South Africa.
[3]International Center for Tropical Agriculture (CIAT), A. A. 6713, Cali, Colombia.
[4]United States Department of Agriculture, Agricultural Research Service, Plant Polymer Research Unit, National Center for Agricultural Utilization Research, 1815N, University of St., Peoria, IL 61604, USA.

Received 23 May, 2017; Accepted 19 July, 2017

A study was conducted to identify the most productive cultivars and their cutting management to optimize nutrient productivity in semi-arid areas of Rwanda. Four cultivars of *Brachiaria brizantha* (Piatá, MG4, Marandú and Xaraes), two cultivars of *Brachiaria humidicola* (Llanero and Humidicola), two cultivars of *Brachiaria* hybrid (Mulato and Mulato II) and one cultivar of *Brachiaria decumbens* (Basilisk) were evaluated against Napier grass (*Pennisetum purpureum*) in an on-farm trial in a complete randomised block design with four replicates. Forage samples were collected at 60, 90 and 120 days after planting (DAP) and analysed for dry matter (DM), crude protein (CP), organic matter (OM) and neutral detergent fibre (NDF). The nutritional values were also estimated using *in vitro* gas production (IVGP) and its kinetic parameters, *in vitro* apparent degradable dry matter (ivADDM), digestible organic matter (DOM), metabolisable energy (ME), partitioning factor (PF) and degradable efficiency factor (DEF). For all cultivars and species, the DM, CP, OM, ivADDM and DOM increased from 60 to 90 DAP and declined thereafter. The NDF contents increased with increase in plant age. Grasses cut at 90 DAP had the highest gas production. The ME differed among grasses and DAP where Piatá had the highest. Furthermore, degradability parameters (A, B, C) and half time ($T_{1/2}$) differed among grasses and between cutting times. The PF and DEF were correlated with ME. The most promising cultivars were Basilisk, Marandú, Piatá and Mulato II because of their high in these nutritional characteristics.

Key words: Chemical composition, metabolisable energy, degradability parameters, degradation efficiency factor.

INTRODUCTION

Intensification of ruminant livestock production is gaining momentum in a number of sub-Saharan African countries due to increasing population pressure and decline in grazing areas (Thornton and Herrero, 2014). Even farmers with access to open grazing land experience frequent feed shortage due to climate change and variability (Chirat et al., 2014).

Feeds and feeding, especially for dairy cows are a

critical issue for smallholder farmers in Rwanda, mostly during the dry season (Klapwijk et al., 2014). In the tropics, grasses are the most ecologically reliable and economically justifiable feed resources (Pedreira et al., 2011) because of their morphological characteristics which enable efficient water use, and rapid recovery after periods of drought (Batistoti et al., 2012). Therefore, improving tropical forages is essential for environmental protection and sustainable livestock feed and food futures for livestock and people (Baudron et al., 2015). *Brachiaria* grasses are among the most important tropical grasses that originated from Africa and improved in Americas through agronomic selection and breeding (Miles et al., 2004). They have demonstrated to be highly productive, nutritive and socially acceptable in Asia and Africa for different livestock production systems (Vendramini et al., 2014).

In tropical areas, the most sensitive attributes to management are metabolisable energy (ME) and crude protein (CP) contents as well as macro and micro-minerals. In case these attributes are low in forages grown in warm-environment, including Napier grass, they can compromise milk yields of cows fed on these forages (Mutimura et al., 2015).

Improved *Brachiaria* grasses are commonly grown in Latin America (Cezário et al., 2015) and these include *Brachiaria brizantha* cv. MG-4, *B. brizantha* cv. Piatá, *B. brizantha* cv. Marandú, *B. brizantha* cv. Xaraes, *B. humidicola* cv. Llanero, *B. humidicola* cv. Humidicola and *B. decumbens* cv. Basilisk which are in general well-adapted to other tropical agro-ecologies. They have recently been introduced, and are being evaluated and disseminated in East Africa (Djikeng et al., 2014).

Results on dry matter production and nutritional quality of some of these grasses have been reported under different cutting regimes of 3, 6, 9 and 12 weeks (Ortega-Gomez et al., 2011). However, the effect of cutting age on nutritional attributes of the mentioned *Brachiaria* cultivars including commercial hybrids (cv. Mulato and cv. Mulato II) during establishment in semi-arid environments in Rwanda has not been determined. The objective of the current study was to identify the best-bet *Brachiaria* cultivars and the based on cutting age to optimize nutrient characteristics and productivity in Rwanda.

MATERIALS AND METHODS

Site description

A field experiment on evaluation of tropical forage grass cultivars was established on-farm (Field trial was established in October 2013 and data recorded until February 2014) in Bugesera district, in the eastern Province (semi-arid area) of Rwanda. Bugesera district lies between 30°25' E and 2°30' S with an average altitude of 1,400 m.a.s.l. The climate is semi-arid with a long (4 to 5 months) dry season (Figure 1). Annual rainfall ranges between 650 and 900 mm, with the average temperature of the coldest month is lower than 18°C.

Land preparation and experimental design

The field trial included a set of nine *Brachiaria* cultivars (*B. brizantha* cv. MG-4, *B. brizantha* cv. Piatá, *B. brizantha* cv. Marandú, *B. brizantha* cv. Xaraes, *B. humidicola* cv. Llanero, *B. humidicola* cv. Humidicola, *B. decumbens*, cv. Basilisk, *Brachairia* hybrid cv. Mulato and *Brachiaria* hybrid cv. Mulato II) together with Napier grass which was used as control, because it is the major feed resource in the area of the study.

The trial was established at on-farm in a randomised complete block design (RCBD) with four replicates. The land used, was before planted to *Lablab purpureus,* a forage legume. The plot was prepared using a hoe, then the plot was divided into sub-plots of 3×3 m. Grasses were established without fertiliser application using seeds and cuttings (for Napier grass with the spacing of 1 m between plants and rows).

For seeds, the sowing was on continuous rows to the rate of 8 kg ha^{-1} with spacing of 50 cm between rows. The experimental design was a split–plot where *Brachiaria* cultivars and Napier grass were the main plots and cutting age of 60, 90 and 120 days after planting (DAP) were subplots. Soil samples were taken and analysed for total nitrogen (N) and soil organic carbon (SOC) contents before planting. Analysis of soil (AOAC, 2006; method ID 984.13) revealed N and SOC contents were 0.3±0.2% and 1.5±0.7%, respectively.

Chemical composition and fibre analyses

Above ground biomass was harvested at each DAP from 1 m^2 quadrat and fresh weight was recorded. Harvested samples of each cutting age were divided into two portions; one portion was dried at 105°C for 24 h to calculate dry matter (DM) contents (AOAC, 1990; method ID 9420.5); and organic matter contents by incineration at 550°C for 8 h (AOAC, 1990; method ID 9420.5). The second portion of these samples was dried at 60°C for 48 h, and then milled to pass through 1 mm screen for subsequent analysis. Crude protein (CP) expressed as 6.25 x Kjeldahl Nitrogen (N kg^{-1} DM) content in the feed (AOAC, 2006; method ID 984.13) using automated systems (Büchi Labortechnik AG, CH-9230 Flawil 1/Switzerland, Type: K-360). Neutral detergent fibre (NDF) was determined according to Van Soest et al. (1991).

In vitro dry matter digestibility and gas production

In vitro gas production (GP) kinetics was measured using automatic-computerised gas production systems (Pell and Schofield, 1993). Ground forage samples (1 g) incubated at 39°C with buffered rumen fluid (100 ml) in Duran bottles (250 ml).

The buffer solutions A and B were prepared according to Osuji et al. (1993). Solution A consisted of sodium hydrogen carbonate

*Corresponding author. E-mail: mupenzimutimura@gmail.com.

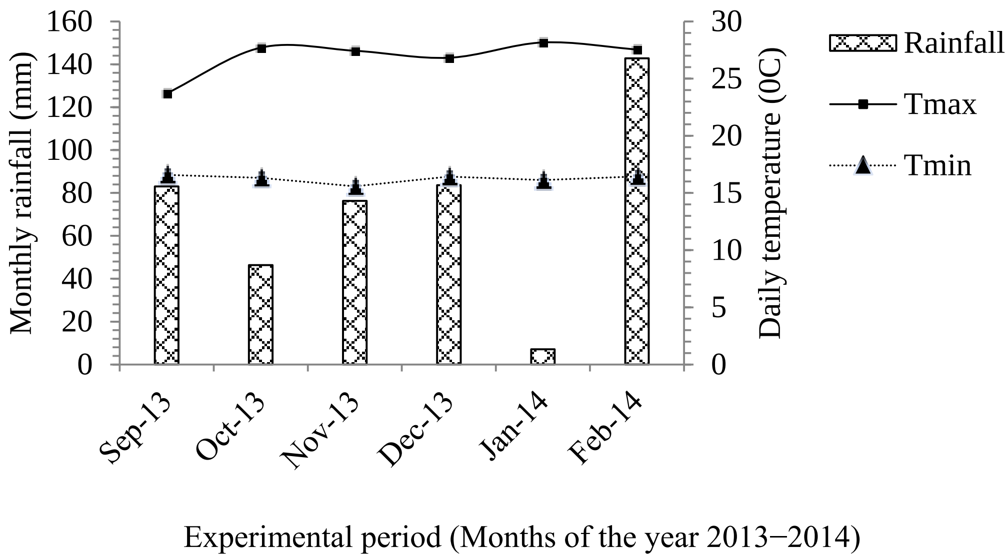

Figure 1. Total monthly rainfall and average daily temperature during the experimental period (Source: Data from Bugesera district weather station)

($NaHCO_3$; 19.6 g), di-sodium hydrogen orthophosphate anhydrous (Na_2HPO_4; 7.4 g); potassium chloride (KCl; 1.14 g); sodium chloride (NaCl; 0.94 g); magnesium chloride hexahydrate ($MgCl_2.6HO_2$; 0.26 g) and distilled water (2 L). Solution B was calcium chloride dihydrate ($CaCl_2.2HO_2$; 2.65 g) dissolved in distilled water (50 ml). An aliquot (2 ml) of solution B was added to solution A. Ammonium sulphate ($(NH_4)_2SO_4$; 5.8 g) was added to the buffer to eke nitrogen requirement for normal rumen microbial function with CO_2.

Two fistulated cows fed *ad libitum* veld hay and Lucerne supplement (2 kg day^{-1}) provided rumen liquor. The rumen content was macerated in a plastic bucket under CO_2 flux. The rumen fluid was squeezed through four layers of cheesecloth. The resultant liquor was transferred into a warm vacuum flask for delivery to the laboratory within 20 minutes. The final inoculum was made by adding the buffer solution (67 ml) and rumen liquor (33 ml) to the sample (1 g) in the Duran bottle (250 ml) under continuous CO_2 flux. Pressure readings were recorded at 20 min interval for 72 h.

These bottles were removed and their contents transferred into Beckman bottles for centrifugation ($BECKMAN_{TM}$, JLA-16.250, Max 16000 RPM, S/N 13U5193) at 16,000 rpm for 15 minutes at 4°C. Supernatants were discarded and pellets were quantitatively recovered for DM determination by oven drying to constant weight at 60°C for 72 h (Castells et al., 2012).

Statistical analysis

Cumulative gas volumes were computed for each channel of pressure sensor as the difference between the readings at time (t_i) and the initial reading (t_0), adjusted for control readings (Blank) at corresponding recording times. To determine kinetics of gas volume production combined models (Schofield et al., 1994; Equation 1) were used.

$$W = \frac{G}{1+e^{[2+4c(lt-t)]}} \quad (1)$$

W: Total gas volume at time t; G: Maximum gas volume at $t=\infty$; c: Degradation rate (h^{-1}); lt : Bacteria colonisation or lag time.

Maximum rate of GP at the point of inflection was calculated from the cumulative gas production while the time taken to produce half of gas volume ($T_{½}$) was estimated based on Sahoo et al. (2010)-Equation 2. Rumen degradability efficiency factor (DEF) was also calculated based on Ouda and Nsahlai (2009)-Equation 3.

$$T_{1/2}\ (h) = lt + 1/(2\times c) \quad (2)$$

$$DEF = \frac{2PF}{T_{1/2}} \quad (3)$$

Where PF is a partitioning factor

The model was run using NEWAY1.SAS (SAS, 2010) which also estimated asymptotic gas production as proxy indicators for organic matter degradability. Organic matter degradability (OMD) and metabolisable energy (ME) values were estimated from *in vitro* digestibility using the following equations (Menke et al., 1979; Equation 4 and 5):

$$OMD\ (g\ kg\text{-}1\ DM) = 14.88+0.889V_{24}+0.45CP+0.0651Ash \quad (4)$$

$$ME\ (MJ\ kg^{-1}\ DM) = 2.2+0.136V_{24}+0.057CP+0.0029CP^2 \quad (5)$$

Where V_{24} = gas volume (ml) at 24 h; CP: crude protein (%). *In vitro* apparent digestible dry matter (ivADDM) was calculated as follows (Equation 6):

ivADDM (g kg^{-1} DM) = [Feed incubated−(Residue–Blank)]* 1000/Feed incubated (6)

Differences in chemical composition and in biological measures among forage cultivars and cutting ages were statistically examined using the general linear model (Equation 7) procedures of SAS (SAS, 2010).

$$Y_{ijk} = \mu + B_i + F_j + H_k + FH_{jk} + \varepsilon_{ijk} \quad (7)$$

Y_{ijk} = variable dependent; μ= overall mean; B_i = effect of block; F_j = effect of forage grass species; H_k = effect of cutting age; FH_{jk} = effect of interaction of $F \times H$; ε_{ijk} = residual error.

A relationship was established between PF and DEF; and ME of these grasses, using regression procedures. This is to determine if the ME can be estimated by using PF and DEF.

RESULTS

Chemical composition

DM was different among grass cultivars across cutting age and at the interaction between cutting age and grass cultivars (P<0.001, Table 1). The DM increased up to 90 DAP and declined at 120 DAP. *Brachiaria* hybrid cv. Mulato II had the highest and Napier grass had the lowest DM contents (Table 1).

A cluster of three cultivars (MG-4, Basilisk and Piatá) had the second highest DM contents which were not different (*P*>0.05) within the same cluster. Cultivars Marandú and Llanero had the second lowest DM contents but not different (*P*>0.05) from DM contents in Mulato, Humidicola and Xaraes (Table 1).

Organic matter content also differed (P<0.001) among grasses and between cutting ages. However, the interaction between cutting age and grass cultivars was not significant (*P*>0.05, Table 1). Organic matter content increased from 60 DAP to 90 DAP and declined at 120 DAP. This trend was consistent in all except three entries (MG-4, Mulato and Napier grass), where OM contents increased with increase in DAP (Table 1).

In addition, CP content differed (*P*<0.01) among grasses, between cutting ages (P<0.001) as well as the interaction. The CP contents between Napier grass and among two cultivars of *Brachiaria* were very strong (P<0.001). Cultivars Humidicola and Piata had the highest but similar CP contents to three cultivars of *Brachiaria* (Marandú, Llanero and Basilisk). *Brachiaria* hybrid cv. Mulato II had the least but similar (*P*>0.05) CP contents to *Brachiaria* hybrid cv. Mulato and Napier grass. The other entries were cultivars with intermediate CP contents (Table 1).

Crude protein contents declined with DAP and this effect was highly significant (P<0.001). However, these responses were dependent on the cultivars and the interaction effect (*P*<0.05). This interaction effect showed that cv. Humidicola, cv. Llanero, cv. Mulato and Napier grass lost more CP between 60 and 90 than they did between 90 and 120 DAP (Figure 2). Conversely, cv. Basilisk, cv. Marandú, cv. MG-4 and cv. Mulato II, cv. Piatá and cv. Xaraes lost more CP between 90 and 120 DAP than they did between 60 and 90 DAP.

Neutral detergent fibre (NDF) of tested grasses differed (P<0.001) among grass cultivars, across cutting age and at the interaction between cutting age and grass cultivars. The NDF contents differed highly (P<0.001) between Napier grass and among *Brachiaria* cultivars. However, cv. Llanero, cv. Mulato and cv. Mulato II had the similar (*P*>0.05) NDF contents and these values were higher than those of Napier grass and other *Brachiaria* cultivars, followed by cultivar Xaraes (Table 1). Neutral detergent fibre contents also increased with DAP (P<0.001). However, the magnitude of change depended on the cultivar. In one cultivar (Basilisk), NDF content decreased by 7 to 8% with DAP from 60 to 120. There was a slight (2%) decrease in cultivar Llanero between 60 and 90 days, thereafter it increased slightly (9%).

In cultivar MG-4, NDF content decreased by approximately 25% from 60 DAP to 90 DAP and rebounded by 44% from 90 DAP to 120 DAP, which making a net gain of approximately 7% from the NDF content at 60 DAP to 120 DAP. Napier grass, Mulato II, Piatá and Xaraes gained (19 to 30%) large fibre content between 60 and 90 DAP compared to subsequent increases at 120 DAP. Successive increases in fibre contents in other cultivars were small (Table 1).

The ivADDM, OMD and ME of tested grasses

There was no difference (*P*>0.05) in ivADDM among grass cultivars although the tendency (*P*=0.051) was very strong at 90 DAP with cultivar Piatá being the highest in ivADDM. However, the DAP (P<0.001) and the effect of the interaction between DAP and genotypes affected ivADDM. Generally, although there was no effect (*P*>0.05) of grass genotypes the trend showed that ivADDM increased from 60 to 90 DAP, then decreased to 120 DAP.

Organic matter digestibility content differed (P<0.001) among grass genotypes (Table 2). The effect of DAP was also high (P<0.001) whereas the effect of the interaction between DAP and grass genotypes was evident (*P*<0.05). In all grasses except cv. Humidicola, OMD increased from 60 to 90 DAP and substantially decreased at 120 DAP. At 90 DAP cv. Piatá had the highest OMD but similar to other grasses except cv. Xaraes and cv. Marandú.

In addition, ME of tested grasses differed among grasses and among DAP (P<0.001). Also, the effect of interaction between DAP and grass genotypes was evident (*P*<0.05; Table 2). At 90 DAP, most grasses had

Table 1. Mean dry matter (DM), OM, CP and NDF (g kg^{-1} DM) of Napier grass and *Brachiaria* cultivars when harvested at 60, 90 and 120 days after planting in semi-arid zone.

DAP	Grass cultivar	DM	OM	CP	NDF
60	Basilisk	133	873	182	349
	Humidicola	153	851	211	310
	Llanero	140	843	187	419
	Marandú	139	852	170	265
	MG-4	147	861	170	300
	Mulato	206	871	173	398
	Mulato II	257	899	147	345
	Napier grass	123	850	182	273
	Piatá	161	886	192	269
	Xaraes	148	877	161	294
90	Basilisk	324	907	167	321
	Humidicola	223	902	152	335
	Llanero	257	889	152	409
	Marandú	279	889	159	275
	MG-4	342	904	156	224
	Mulato	201	882	138	429
	Mulato II	279	916	137	412
	Napier grass	153	890	137	358
	Piatá	291	901	166	334
	Xaraes	281	904	143	382
120	Basilisk	255	901	112	297
	Humidicola	280	865	131	353
	Llanero	227	880	146	444
	Marandú	208	890	138	339
	MG-4	239	905	133	323
	Mulato	240	883	122	440
	Mulato II	304	894	114	457
	Napier grass	191	909	120	367
	Piatá	249	899	133	378
	Xaraes	228	901	120	449
-	SEM	3.2	2.7	2.2	5.7
	Grass cultivars	***	***	**	***
	DAP	***	***	***	***
	DAP × Grass cultivars	***	NS	*	***

DAP: Days after planting; DM: Dry matter; OM: Organic matter; CP: Crude protein; NDF: Neutral detergent fibre; SEM: Standard error of the means; NS: Not significant (P>0.05); ***: Significant (P<0.001); **: Significant (P<0.01); *: Significant (P<0.05).

similar ME except cv. Piatá and cv. Xaraes which had the highest and lowest levels, respectively.

Cumulative GP was different (P<0.01) among grasses and highly (P<0.001) among DAP (Table 3); however, interaction between grass cultivars and DAP was not different (P>0.05). The GP of grasses cut at 90 DAP was higher than at 60 and 120 DAP. Degradability showed similar (P>0.05) quickly degradable fraction (A) among tested grasses but differed (P<0.001) among different DAP. Thus, grass harvested at 60 and 90 DAP had highest A compared to grass cut at 120 DAP.

Furthermore, there was no (P>0.05) interaction between

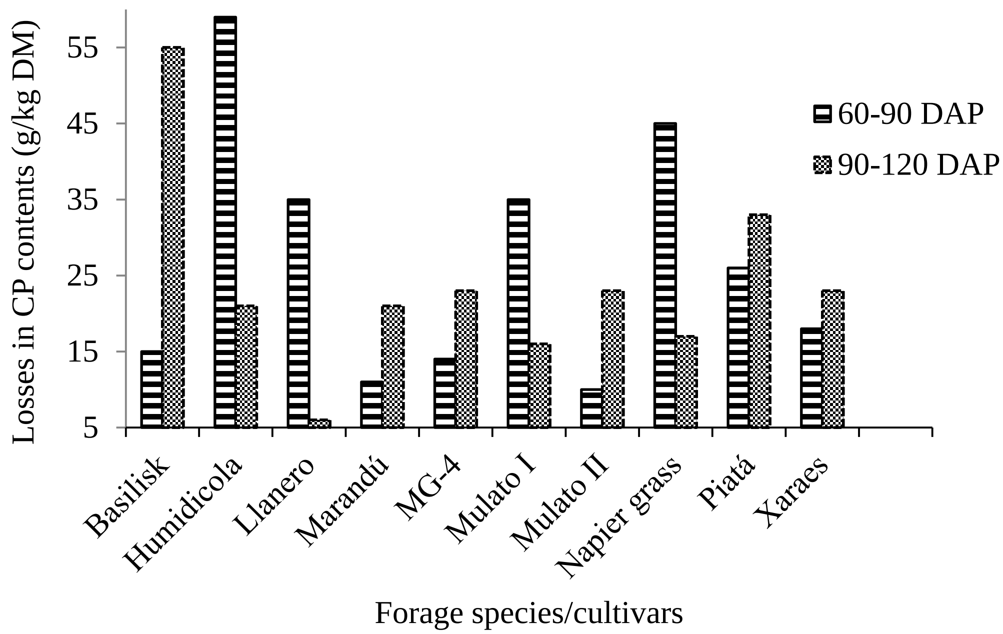

Figure 2. Effect of the age of the plant on losses in CP contents in different cultivars of *Brachiaria* and Napier grass.

cultivars and DAP on A and B. Conversely, slowly degradable fraction (B) differed modestly (P<0.01) among grasses and highly (P<0.001) among DAP. In addition, the rate of degradation (C) of B differed modestly (P<0.01) among grass cultivars and highly (P<0.001) among DAP. The interaction between grass cultivars and DAP affected (P<0.01) the rate of degradation. Higher rates of degradation of tested grasses were observed at 60 DAP while the lowest were observed at the age of 120 DAP.

Furthermore, half-life ($T_{1/2}$) differed (P<0.01) among grass cultivars and highly (P<0.001) among DAP. The interaction between grass cultivars and DAP affected (P<0.01) $T_{1/2}$ at 120 DAP while $T_{1/2}$ of 60 DAP did not differ from that of 90 DAP.

Partitioning factor (PF) and rumen degradability efficiency factor (DEF) showed correlation (R^2= 0.86; R^2=0.89) with metabolisable energy (ME; Figure 3a, b) of tested grass cultivars. Also, there was a very strong positive correlation (R^2= 0.96) between DEF and PF (Figure 3c).

DISCUSSION

Dry matter content in most tested forage grasses increased from 60 to 90 DAP and declined at 120 DAP for cv. Humidicola, cv. Mulato, cv. Mulato II and Napier grass. At 90 DAP where grasses had higher DM contents, cv. MG-4, cv. Basilisk and cv. Mulato II had greater values.

Previous researchers have reported that DM content is much influenced by genetic makeup of the plant, weather and postharvest handling. For example, the DM of Napier grass obtained at 60 DAP was much lower than that reported in the same grass at the same growth stage (Zetina-Córdoba et al., 2013). This difference might be due to the fact that the grass in Thailand was grown with fertiliser application (NPK, 15-15-15; kg ha^{-1}) whereas in this study, tested grasses were established without any fertiliser application. The DM content observed at 90 DAP in this study was similar to that reported on forage cereal crops in eastern China (Qu et al., 2014).

The DM of tested grasses revealed that a good time for high DM concentration was at 90 DAP. For warm-season grass, temperatures below 15°C can decrease growth of the grass (Moreno et al., 2014). Temperatures throughout our experiment were above 15°C. For this reason, high DM obtained at 90 DAP might be influenced by the low moisture as the samples at this age were collected during dry season compared to other DAP. However, Napier grass which is the most popular forage cultivar used by farmers in east Africa including Rwanda to feed cattle (Klapwijk et al., 2014) had the lowest DM at 90 DAP. This suggests that tested *Brachiaria* cultivars might offer more advantages on nutritional characteristics than Napier grass at 90 DAP.

Increase of CP level in a feed should come from conventional feed resources (Baluch-Gharaei et al., 2015). The CP content of most grasses decreased with

Table 2. Mean values of ivADDM, OMD and ME for the tested grasses at different days after planting.

DAP	Grass cultivar	ivADDM (g kg^{-1} DM)	OMD (g kg^{-1} DM)	ME (MJ kg^{-1} DM
60	Basilisk	251	417	6.9
	Humidicola	378	480	8.2
	Llanero	313	537	8.7
	Marandú	349	422	6.8
	MG-4	364	466	7.5
	Mulato	507	537	8.7
	Mulato II	318	493	7.8
	Napier grass	336	445	7.3
	Piatá	334	469	7.8
	Xaraes	320	447	7.2
90	Basilisk	524	523	8.4
	Humidicola	550	467	7.4
	Llanero	508	489	7.7
	Marandú	465	437	7.0
	MG-4	412	510	8.1
	Mulato	495	494	7.7
	Mulato II	457	509	8.0
	Napier grass	351	453	7.1
	Piatá	564	550	9
	Xaraes	455	433	6.8
120	Basilisk	318	352	5.4
	Humidicola	400	470	7.3
	Llanero	433	427	6.7
	Marandú	337	369	5.9
	MG-4	445	410	6.5
	Mulato	348	474	7.3
	Mulato II	490	416	6.4
	Napier grass	486	378	5.9
	Piatá	429	397	6.3
	Xaraes	296	378	5.9
-	SEM	24.6	12.1	0.2
	Grass cultivars	NS	***	***
	DAP	***	***	***
	DAP × Grass cultivars	*	*	**

DAP: Days after planting; ivADDM: *In vitro* apparent degradable dry matter; OMD: Organic matter digestible; ME: Metabolisable energy; SEM: Standard error of the means; NS: Not significant (P>0.05); ***: Significant (P<0.001); **: Significant (P<0.01); *: Significant (P<0.05).

advancing age of plants. These differences in CP losses within cultivars among DAP were large in cv. Basilisk, cv. Humidicola, cv. Llanero and Napier grass than other cultivars within DAP. This implies some forage cultivars (for example, cv. Humidicola, cv. Llanero and cv. Mulato) should be harvested earlier than the other (e.g. cv. Basilisk, cv. Marandú, cv. MG-4 and cv. Mulato II) to maximise forage CP. It would be better to harvest cv. Piatá and cv. Xaraes between 60 and 90 DAP than other cultivars, especially cv. Basilisk. The CP at 90 DAP ranged between 137 and 167 g kg^{-1} DM and were much higher than the CP content (109 g kg^{-1} DM) reported from Brazil in *Brachiaria brizantha* when the grass was intercropped with soybean (Crusciol et al., 2014). These

Table 3. *In vitro* digestion parameters of experimental grasses cut at 60, 90 and 120 days after planting.

DAP	Grass cultivar	GP (ml g^{-1} DM)	A (g kg^{-1} DM)	B (g kg^{-1} DM)	C (% h^{-1})	$T_{1/2}$
60	Basilisk	168	60	108	0.031	23
	Humidicola	182	73	110	0.039	20
	Llanero	199	50	149	0.033	24
	Marandú	163	58	106	0.036	22
	MG-4	211	71	140	0.028	21
	Mulato	222	74	147	0.03	20
	Mulato II	215	86	129	0.035	20
	Napier grass	196	62	134	0.032	23
	Piatá	212	69	143	0.03	23
	Xaraes	197	68	129	0.31	23
90	Basilisk	240	70	170	0.033	20
	Humidicola	216	61	155	0.033	22
	Llanero	253	86	168	0.028	21
	Marandú	188	65	124	0.028	22
	MG-4	234	87	148	0.028	20
	Mulato	253	96	155	0.029	19
	Mulato II	243	66	177	0.029	19
	Napier grass	243	65	178	0.028	26
	Piatá	266	69	197	0.032	20
	Xaraes	210	50	160	0.025	23
120	Basilisk	182	36	147	0.028	29
	Humidicola	243	51	192	0.027	23
	Llanero	255	53	201	0.023	23
	Marandú	163	37	130	0.031	27
	MG-4	190	47	143	0.03	25
	Mulato	224	52	172	0.027	20
	Mulato II	198	46	152	0.027	23
	Napier grass	198	39	164	0.032	28
	Piatá	192	40	152	0.029	26
	Xaraes	198	30	169	0.021	29
-	SEM	8.4	5.3	7.6	0.001	0.5
	Grass cultivars	**	NS	**	**	***
	DAP	***	***	***	***	***
	DAP × Grass cultivars	NS	NS	NS	**	**

DAP: Days after planting; GP: Gas production; A: intercept (quick degradable fraction); B: Potential degradable (slow degradable fraction); C: rate of degradability of B; $T_{1/2}$ (h): half time (time taken to produce half of gas volume); ***: Significant (P<0.001); **: Significant (*P*<0.01); NS: Not significant (*P*>0.05).

results obtained for CP content on cv. Piatá, cv. Marandú and cv. Xaraes were also higher than those reported in Brazil when these grasses were subjected to cutting heights of 10, 20 and 30 cm above the soil (de Pinho Costa et al., 2014).

However, results from this study were similar to those of Maia et al. (2014) where inorganic fertiliser (nitrogen and phosphorus) was applied to same grasses after corn was harvested. In addition, the CP contents in cv. Marandú were much higher (170 g kg^{-1} DM) than those reported in Brazil where cv. Marandú (66 g kg^{-1} DM) was harvested at 60 DAP and fed to steers (Morais et al., 2011).

This might be due to the soil structure, management practices and weather conditions which are major factors that influence nutritional quality of grasses. The CP values

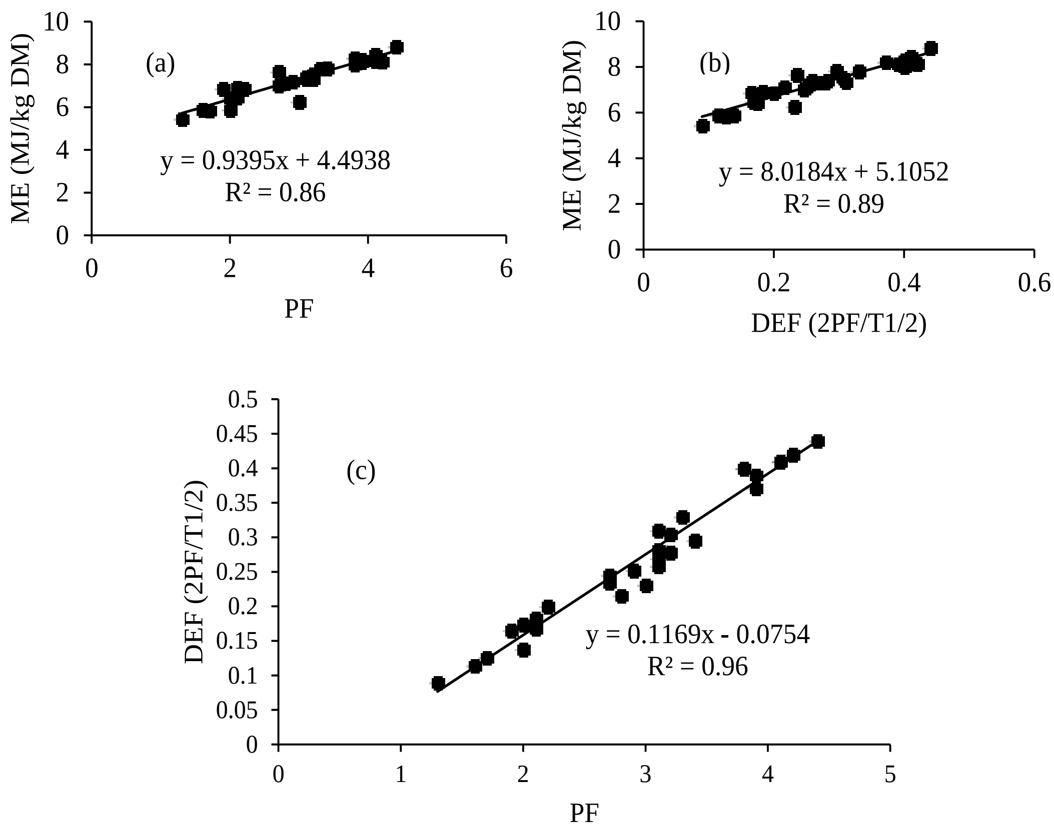

Figure 3. Relationship between ME and PF (a), between ME and DEF (b) and between DEF and PF (c) of tested grass cultivars.

obtained in Napier grass were much higher than CP values (112 g kg^{-1} DM) of the grass reported in Taiwan at 60 days of growth (Zetina-Córdoba et al., 2013).

In addition, at 60 days of age, cv. Humidicola had higher CP (211 g kg^{-1} DM) than the rest of these grasses. This could be due to its low germination rates and slower growth under cooler environment (Meena et al., 2014) which might influence its CP in leaves at 60 DAP. At 90 DAP cv. Piatá and cv. Basilisk had high values of CP of 166 and 167 g kg^{-1} DM, respectively. This could satisfy the daily CP requirement of a lactating cow producing 20 to 30 L of milk per day (NRC, 2001). Our findings suggest that tested *Brachiaria* grasses, in the short run, can be a good source of CP to cattle without any fertiliser application in local farm prevailing conditions.

The NDF content in feed is one of the major criteria to predict DM intake (DMI) in animal, especially for grazing animals. This is because high NDF content in a feed leads animal to eat less feed (Lardner et al., 2015) and hence affects animal productivity. The NDF content in tested grasses increased with DAP. Cultivars Llanero, Mulato and Mulato II showed higher NDF contents than the rest of these grasses across the three DAP. The NDF content observed in most grasses within each DAP was much lower than values reported in other grasses like *Lilum* sp. (Fukushima et al., 2015).

The NDF reported in Taiwan on Napier grass was much higher (710 g kg^{-1} DM; Zetina-Córdoba et al., 2013) when compared to this study results. Cultivars Piatá, MG-4, Xaraes and Marandú showed lower NDF content at all three DAP than values reported in Brazil when these grasses were harvested during four seasons of the year (de Pinho Costa et al., 2014).

When comparing cutting ages, NDF was much higher (385 g kg^{-1} DM) at 120 DAP, however, these values are in the range of 300 to 400 g kg^{-1} DM which is the recommended NDF content in feed for good DMI by ruminant livestock (McDonald et al., 2011). Furthermore, OM content of forage grasses used in this study increased from 60 to 90 DAP. However, except cv. Basilisk, cv. Humidicola, cv. Llanero and cv. Mulato II, OM content of the rest of the tested grasses declined at 120 DAP.

Generally, the mean OM content of tested grasses at 90 DAP was higher (898 g kg^{-1} DM) than that of 60 DAP (866 g kg^{-1} DM) and 120 DAP (893 g kg^{-1} DM). These values of OM content in tested grasses were similar to those reported in meadow grasses (91.3%) in Armenia

(Khachatur, 2006). However, OM values of Napier grass were similar (891 g kg^{-1} DM) to those reported in Taiwan on Napier grass at the age of 60 days of growth (Zetina-Córdoba et al., 2013).

Dry matter digestibility is one of many factors influencing animal productivity (Mathison et al., 1995). This is also influenced by the availability of the degradable materials of the feed (Campos et al., 2013). The ivADDM of tested grasses differed at 90 and 120 DAP. High ivADDM of these grasses was obtained at 90 DAP. This might be due to the high DM content at this age of harvest. At 120 DAP, ivADDM decreased except for cv. MG-4, Napier grass and cv. Mulato II. Most grasses showed low ivADDM with values below 50% except for cv. Piatá, cv. Humidicola, cv. Basilisk and cv. Mulato which had 564; 550; 524 and 508 g kg^{-1} DM, respectively at 90 DAP.

Similar results were reported on *Saccharum officinarum* and *Panicum maximum* by Singh et al. (2012), but these were lower than results reported in Brazil using the same *Brachiaria* cultivars (Maia et al., 2014). Our results on ivADDM from Napier grass were lower than reported by Singh et al. (2014).

In addition, OMD increased with cutting age of these grasses until 90 DAP and declined at 120 DAP. These same grasses had high OMD at 90 DAP. The high OMD in cv. Piatá, cv. Basilisk and cv. MG-4 could be explained by their high CP contents (Sampaio et al., 2010) at 90 DAP with reasonable values of NDF content in grasses. Other researchers have reported high OMD (>64%) in cv. Mulato II and cv. Cayman (Vendramini et al., 2014).

The OMD in cv. Humidicola was higher than that reported by Nogueira Filho et al. (2000) in the same grass but lower than in Napier grass. Furthermore, ME in tested grasses at 60 and 90 DAP did not differ. However, high ME (9 MJ kg^{-1} DM) was obtained in cv. Piatá cut at 90 DAP followed by cv. Basilisk, cv. MG-4 and cv. Mulato II. The ME values observed in these grasses were higher than those reported on available forage grasses in smallholder farms in Rwanda (Mutimura et al., 2015).

Instead, these grasses showed similar ME content compared to some temperate grass cultivars (Fulkerson et al., 2007). The Napier grass which is considered as control had similar ME content reported by latter authors. Although there was variation in ME content among tested grasses, some of these grasses might not satisfy the ME requirement for dairy cow with live weight of 450 kg producing 20 to 30 L of milk per day (NRC, 2001). Nevertheless, cv. Piatá can meet the daily ME requirement for dairy cow of 650 kg live weight producing 16 L per day (Geraghty et al., 2010) if it can eat 17 kg of DM per day. Moreover, grasses with ME above 7 MJ kg^{-1} DM might be better to supply energy to ruminant livestock based on dairy dry matter intake (Datt et al., 2008).

Gas production parameters of a feed are crucial factors in animal nutrition because they can be used to predict dry matter intake by the animal. Gas production (GP), rate of degradability and half time ($T_{1/2}$) of grasses were higher at 90 than at 60 and 120 DAP. Cultivar Piatá had the highest GP at 90 DAP followed by Mulato. This might be due to high DM content in the grass at 90 DAP. The B of cv. Piatá was also higher than that of other grasses which revealed that this grass cultivar had a high degradable fraction. Interestingly, the rate of degradation in cv. Piatá was also high although similar to cv. Basilisk and cv. Humidicola. The high rate of degradation might be influenced by the high energy content of these grasses.

Negrão et al. (2014) reported that the increase of rate of degradation in cv. Basilisk was influenced by increasing levels of rice bran as source of energy. The rate of degradation of cv. Mulato II and cv. Basilisk was much lower than that reported in previous research on Napier grass (Mutimura et al., 2015). The time taken to produce half of gas volume ($T_{1/2}$) suggests that cv. Piatá, cv. Mulato, cv. Mulato II, cv. MG-4 and cv. Basilisk might serve as a good source of forage which can increase DMI by the animal. Furthermore, although Napier grass had reasonable degradable fractions, it required a longer time (26 h) to be degraded than the other grasses. This means that at this growth age the DM intake of Napier grass by a ruminant livestock might be reduced due to the extended length of time taken in the rumen (Negrão et al., 2014).

The DEF which is influenced by the time to produce half of gas volume, was correlated with ME. The ME increased with increase of PF as well as with the increase of DEF. Similar trend was observed by Ouda and Nsahlai (2009) who reported the increase of DEF of grass hay when supplementation ratio of legumes was increasing. As the DEF is a proportional of PF and $T_{1/2}$, forages with small values of $T_{1/2}$ will have high values of DEF. Also, when $T_{1/2}$ remains constant, DEF increases with increase of PF. This means that high rumen degradability depicts microbial efficiency and high values of ME in a forage grass indicating that the ME can be estimated using DEF and PF.

Conclusion

Among 10 grasses tested there were significant differences in terms of nutritional characteristics across the cutting ages. Most grasses had slightly similar nutritive values but cv. Marandú, cv. Basilisk and cv. Piatá were superior in nutritional attributes compared to the rest of these grasses. This is because their DM contents were not higher but their ivADDM, GP, potential degradable fractions, DEF, ME and time taken for rumen degradability values were superior to the rest. Napier grass as the major feed resource of smallholder farmers in east Africa was found to be among the lowest in its

nutritive value attributes among the tested grasses. The ME contents decreased from 90 to 120 DAP. The most promising *Brachiaria* cultivars identified were *B. decumbens* cv. Basilisk, *B. brizantha* cv. Marandú and *B. brizantha* cv. Piatá, because of their nutritional characteristics which were higher than the other cultivars. Although these *Brachiaria* grasses have shown good nutritional quality, evaluation of their effect on livestock performance is of great importance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

Authors are grateful for the financial support from Swedish International Development Agency (Sida) funded project on "Climate-smart *Brachiaria* grasses to improve livestock production in East Africa" through Biosciences for eastern and central Africa under International Livestock Research Institute (BecA-ILRI), Nairobi, Kenya.

REFERENCES

Association of Official Analytical Chemists (AOAC) (1990). Association of official Analytical chemists. Official methods of analysis. 15th edition. A.O.A.C. Arlington Virginia, USA.

Association of Official Analytical Chemists (AOAC) (2006). Total nitrogen, Official Methods of analysis, 984.13, 18th edition. Association of official analytical chemists, Washington, DC.

Baluch-Gharaei H, Rouzbehan Y, Fazaeli H, Rezaei J (2015). Effect of deep-stacking broiler litter on pathogenic bacteria, intake, digestibility, microbial protein supply and rumen parameters in sheep. Anim. Feed Sci. Technol. 199:73-83.

Batistoti C, Lemppa B, Jank L, das Morais MG, Cubas AC, Gomes RA, Ferreira MVB (2012). Correlations among anatomical, morphological, chemical and agronomic characteristics of leaf blades in *Panicum maximum* genotypes. Anim. Feed Sci. Technol. 171:173-180.

Baudron F, Mamo A, Tirfessa D, Argaw M (2015). Impact of farmland exclosure on the productivity and sustainability of a mixed crop-livestock system in the Central Rift Valley of Ethiopia. Agric. Ecosyst. Environ. 207:109-118.

Campos FP, Sarmento P, Nussio LG, Lugão SMB, Lima CG, Daniel JLP (2013). Fibre monosaccharides and digestibility of Milenio grass under N fertilization. Anim. Feed Sci. Technol. 183:17-21.

Castells L, Bach A, Araujo G, Montoro C, Terré M (2012). Effect of different forage sources on performance and feeding behaviour of Holstein calves. J. Dairy Sci. 95:286-293.

Cezário AS, Ribeiro KG, Santos SA, de Campos Valadares Filho S, Pereira OG (2015). Silages of Brachiaria brizantha cv. Marandú harvested at two regrowth ages: microbial inoculant responses in silage fermentation, ruminant digestion and beef cattle performance. Anim. Feed Sci. Technol. 208:33-43.

Chirat G, Groot JCJ, Messada S, Bocquier F, Ickowicz A (2014). Instantaneous intake rate of free-grazing cattle as affected by herbage characteristics in heterogeneous tropical agro-pastoral landscapes. Appl. Anim. Behav. Sci. 157:48-60.

Crusciol CAC, Nascente AS, Mateus GP, Pariz CM, Martins PO, Borghi E (2014). Intercropping soybean and palisade grass for enhanced land use efficiency and revenue in a no till system. Eur. J. Agron. 58:53-62.

Datt C, Datta M, Singh NP (2008). Assessment of fodder quality of leaves of multipurpose trees in subtropical humid climate of India. J. Forest. Res. 19:209-214.

de Pinho Costa KA, da Costa Severiano E, Simon GA, Epifanio PS, da Silva AG, Guedes Fonseca Costa RR, Santos CB, Rodrigues CR (2014). Nutritional characteristics of *Brachiaria brizantha* cultivars subjected to different intensities cutting. Am. J. Plant Sci. 5:1961-1972.

Djikeng A, Rao IM, Njarui D, Mutimura M, Caradus J, Ghimire SR, Johnson L, Cardoso JA, Ahonsi M, Kelemu S (2014). Climate-smart *Brachiaria* grasses for improving livestock production in East Africa. Trop. Grasslands- Forrajes Trop. 2(1):38-39.

Fukushima RS, Kerley MS, Ramos MH, Porter JH, Kallenbach RL (2015). Comparison of acetyl bromide lignin with acid detergent lignin and Klason lignin and correlation with in vitro forage degradability. Anim. Feed Sci. Technol. 201:25-37.

Fulkerson WJ, Neal JS, Clark CF, Horadagoda A, Nandra KS, Barchia I (2007). Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: Grasses and legumes. Livest. Sci. 107:253-264.

Geraghty T, O'Grady L, Mulligan FJ (2010). An investigation into reduced milk production following dietary alteration on an Irish dairy farm. Irish Vet. J. 63:689-694.

Khachatur MB (2006). *In- vitro* digestible organic matter and energy contents in wild growing forages of Armenia. J. Central Eur. Agric. 7:445-450.

Klapwijk CJ, Bucagu C, van Wijk MT, Udo HMJ, Vanlauwe B, Munyanziza E, Giller KE (2014). The 'One cow per poor family' programme: Current and potential fodder availability within smallholder farming systems in southern Rwanda. Agric. Syst. 131:11-22.

Lardner HA, Damiran D, McKinnon JJ (2015). Evaluation of 3 bromegrass species as pasture: Herbage nutritive value, estimated grass dry matter intake and steer performance. Livest. Sci. 175:77-82.

Maia GA, de Pinho Costa KA, da Costa Severiano E, Epifanio PS, Neto JF, Ribeiro MG, Fernandes PB, Silva JFG, Gonçalves WG (2014). Yield and chemical composition of *Brachiaria* forage grasses in the offseason after corn harvest. Am. J. Plant Sci. 5:933-941.

Mathison GW, Okine EK, Vaage AS, Kaske M, Millingan LP (1995). Current understanding of the contribution of the propulsive activities in the forestomach to the flow of digesta. In: Engelhardt Wv, Leonhard-Marek S, Breves G, Giesecke D (eds) Ruminant physiology: Digestion, Metabolism, Growth and Reproduction. Proceedings of the eighth International Symposium on Ruminant Physiology. Herstellung: Schröders, Agentur, D-14199, Berlin. pp. 23-41.

McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA, Sinclair LA, Wilkinson RG (2011). Animal nutrition. Seventh Edition, Pearson Education Limited, Edinburgh Gate, Harlow, Essex CM20 2JE, England. 692p.

Meena HM, Sachdev MS, Manjaiah KM, Dotaniya ML (2014). Nitrification Inhibition Potential of *Brachiaria humidicola*. Natl. Acad. Sci. Lett. 37:113-116.

Menke KH, Raab L, Salewski A, Steingass A, Fritz D, Scheinder W (1979). The estimation of digestibility and metabolisable energy contents of ruminant feedstuffs from gas production when they incubated with rumen fluid *in vitro*. J. Agric. Sci. (Cambridge) 92:217-222.

Miles JW, Valle CB do, Rao IM, Euclides VPB (2004). *Brachiaria* grasses. In: Moser, LE, Burson LE, Sollenberger LE (eds) Warm-season (C4) grasses. Agronomy, Monograph 45. ASA, CSSA, SSSA, Madison, WI, USA. pp. 745-783.

Morais JAS, Berchielli TT, de Vega A, Queiroz MFS, Keli A, Reis RA, Bertipaglia LMA, Souza SF (2011). The validity of n-alkanes to estimate intake and digestibility in Nellore beef cattle fed a tropical grass (*Brachiaria brizantha* cv. Marandu). Livest. Sci. 135:184-192.

Moreno LSB, Pedreira CGS, Boote KJ, Alves RR (2014). Base temperature determination of tropical *Panicum* spp. grasses and its effects on degree-day based models. Agric. For. Meteorol. 186:26-33.

Mutimura M, Ebong C, Rao IM, Nsahlai IV (2015). Nutritional values of available ruminant feed resources in smallholder dairy farms in Rwanda. Trop. Anim. Health Prod. 47:1131-1137.

Negrão FM, Zanine AM, Cabral LS, de Souza AL, Alves GR, Ferreira DJ, Dantas CCO, Lehmkuhl A (2014). Fractionation of carbohydrates and protein and rumen degradation kinetic parameters of *Brachiaria* grass silage enriched with rice bran. R. Bras. Zootec. 43:105-113.

Nogueira Filho JCM, Fondevila M, Barrios Urdaneta A, Gonzalez Ronquillo M (2000). In vitro microbial fermentation of tropical grasses at an advanced maturity stage. Anim. Feed Sci. Technol. 83:145-157.

NRC (National Research Council) (2001). Nutrient requirements of dairy cattle. Seventh revised edition, National academy press, Washington, D.C., 381p.

Ortega-Gomez R, Castillo-Gallegos E, Jarillo-Rodríguez J, Escobar-Hernández R, Ocaña-Zavaleta E, Valles de la Mora B (2011). Nutritive quality of ten grasses during the rainy season in hot-humid climate and ultisol soil. Trop. Subtrop. Agro-ecosyst. 13:481-491.

Osuji PO, Nsahlai IV, Khalili H (1993). Feed Evaluation. ILCA Manual 5. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia.

Ouda JO, Nsahlai IV (2009). Relevance and potential use of in vitro gas production measurements to evaluate varying ratios of roughages and protein sources for ruminants. J. Appl. Anim. Res. 35:9-16.

Pedreira BC, Pedreira CGS, Boote KJ, Lara MAS, Alderman PD (2011). Adapting the CROPGRO perennial forage model to predict growth of *Brachiaria brizantha*. Field Crops Res. 120:370-379.

Pell AN, Schofield P (1993). Computerized monitoring of gas production to measure forage digestion *in vitro*. J. Dairy Sci. 76:1063-1073.

Qu H, Liu XB, Dong CF, Lu XY, Shen YX (2014). Field performance and nutritive value of sweet sorghum in eastern China. Field Crops Res. 157:84-88.

Sahoo A, Ogra RK, Sood A, Ahuja PS (2010). Nutritional evaluation of bamboo cultivars in sub-Himalayan region of India by chemical composition and *in vitro* ruminal fermentation. Grassland Sci. 56:116-125.

Sampaio CB, Detmann E, Paulino MF, Valadares Filho SC, de Souza MA, Lazzarini I, Rodrigues Paulino PV, de Queiroz AC (2010). Intake and digestibility in cattle fed low-quality tropical forage and supplemented with nitrogenous compounds. Trop. Anim. Health Prod. 42:1471-1479.

SAS (2010). Statistics, Version 9.3. SAS Institute, Inc., Cary, NC, USA.

Schofield P, Pitt RE, Pell AN (1994). Kinetics of fibre digestion from *in vitro* gas production. J. Anim. Sci. 72:2980-2991.

Singh S, Anele UY, Edmunds B, Südekum K.H (2014). *In vitro* ruminal dry matter degradability, microbial efficiency, short chain fatty acids, carbohydrate and protein fractionation of tropical grass-multipurpose tree species diets. Livest. Sci. 160:45-51.

Singh S, Kushwaha BP, Nag SK, Mishra AK, Singh A, Anele UY (2012). *In vitro* ruminal fermentation, protein and carbohydrate fractionation, methane production and prediction of twelve commonly used Indian green forages. Anim. Feed Sci. Technol. 178:2-11.

Thornton PK, Herrero M (2014). Climate change adaptation in mixed crop–livestock systems in developing countries. Glob. Food Secur. 3:99-107.

Van Soest PJ, Robertson JB, Lewis BA (1991). Methods for dietary fibre, neutral detergent fibre and non-starch carbohydrates in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

Vendramini JMB, Sollenberger LE, Soares AB, Da Silva WL, Sanchez JMD, Valente AL, Aguiar AD, Mullenix MK (2014). Harvest frequency affects herbage accumulation and nutritive value of *Brachiaria* grass hybrids in Florida. Trop. Grasslands – Forrajes Trop. 2:197-206.

Zetina-Córdoba P, Ortega-Cerrilla ME, Ortega-Jiménez E, Herrera-Haro JG, Sánchez-Torres-Esqueda MT, Reta-Mendiola JL, Vilaboa-Arroniz J, Munguía-Ameca G (2013). Effect of cutting interval of Taiwan grass (*Pennisetum purpureum*) and partial substitution with duckweed (*Lemna* sp. and *Spirodela* sp.) on intake, digestibility and ruminal fermentation of pelibuey lambs. Livest. Sci. 157:471-477.